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ABSTRACT

In view of the apparent complexity and dynamism of the learner, only a systems approach to learning processes can provide a viable and practical frame of reference within which to conduct educational research. There are fundamental weaknesses in the current cybernetic model of learning, and therefore, it is useful to consider the learner as an active open system. This approach, drawing frequently upon Piagetian theory, seems to provide a more realistic picture of the autonomous learner and his changing cognitive structures. Von Bertalanffy's equations for the growth of the living organism can form a basis for an open system model of learning. The Model generates learning curves which suggest that a steady state is not always the outcome of learning. Some implications of the model for educational research are briefly examined in this paper. (Author/DC)

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AN OPEN-SYSTEM MODEL OF LEARNING

William Winn

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Abstract.

It is suggested that, in view of the apparent complexity and dynamism of the learner, only a systems approach to learning processes can provide a viable and practical frame of reference within which to conduct educational research. After identifying the weaknesses of the current cybernetic model of learning, an examination is made of the learner as an active open system. This approach, drawing frequently upon Piagetian theory, seems to provide a more realistic picture of the autonomous learner and his changing cognitive structures. An open system model of learning is then suggested. Based on von Bertalanffy's equations for the growth of the living organism, the model generates learning curves which suggest that a steady-state is not always the outcome of learning. Some implications of the model for educational technology research are then briefly examined.

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It is not new to apply systems theory to education. Educational technologists, Ely (1963), Hoban (1963 p. 124) and Heinich (1970) among others, have convinced us that we should take a "systems approach" to education, and have shown us how to. The reasons they put forward for adopting the systems approach lie at the very heart of educational technology. Advances in the quantity and quality of hardware and software have provided education with a variety and flexibility of resources hitherto unknown. Instructional deisgners can now create rich mutlimediated learning systems, where learners have access to information in many different forms. At the same time, the greater choice of media and methods permits the educator to fine-tune instruction to meet the needs of individuals rather than of groups, to match treatments to aptitudes in a more sophisticated way than was formerly possible. The systems approach, argue the experts, provides us with a conceptual framework with which to confront combination and variety in education. It furnishes models and ultimately strategies for the management of learning, and points the way to changes in the role of the instructor. Technology has created a multitude of educational resources. At the same time, technology has furnished ways to plan, integrate and coordinate these resources so that they are both effective and efficient.

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The effectiveness and efficiency of educational systems reposes utlimately on the match made between what Schalock has called the "conditions" and the "processes" of learning (1972, p. 39). It is the task of the educational technologist to reconcile these, that is to manipulate the educational environment in such a way that learning is maximized. Yet the gap between research into the conditions and into the processes of learning is often sufficiently large to prevent this task from being successfully completed. Stowe has suggested a solution to this problem. He suggests both educational research and the systems approach as complementary, though different, educational methodologies (Stowe, 1973). He states that while educational research seeks to obtain refined knowledge and a high degree of statistical confidence in results, the systems approach deals on a less refined level with local real-world situations. It is more concerned with settings than with the experimental manipulation of variables. Furthermore, Stowe's estimation of systems technology as a valuable complement to educational research is based on its operation at the level of whole systems. It provides tools for structuring many variables at once and for studying relationships among elements. It recruits techniques and ideas from many different fields and thus provides a holistic view of what has hitherto been a fragmented area. The general effect of applying systems

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theory to educational research would be to free it from the constraints of the compartmentalized scientific approach which now dominates it, and to make it more directly applicable.

It must not be assumed that all educational research should be "liberated" in this way. Rigour still has an important place. Yet the reality of education is often less amenable to scientific explication than researchers would have us believe -- a fact that emerges frequently during discussions of how learning theory relates to instructional strategy, (for example, Hudgins, 1971, pp. 3-7 and 26). The great advantage of the systems approach is therefore its broader perspective which allows the consideration of certain realistic learner characteristics that traditional educational research sometimes has to ignore, but which are nonetheless essential to an understanding of the behavior of the learner. Let us mention three of these characteristics:

1. The learner is active. Research into physiological psychology reported by Hunt (1961), Lorenz (1966), Hebb (1949), Pribram (1960) and summarized in Butcher (1968, pp. 138-141), has painted a new picture of the brain as being in a normal state of continuous activity. This idea of activity has carried over into cognitive psychology, notable the genetic epistemology of Piaget. The learner can no longer be considered as a passive recipient of information, but rather

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as participating actively in learning. The outcomes of learning are therefore less scientifically predictable.

2. All of what is learned cannot be measured. Positions on this question are easing, but education is still largely dominated by the precept, "if it cannot be measured, it cannot be taught". As a result, much of educational endeavor has been limited to, say, the lower types of learning in Gagné's hierarchy (1970). What Mitchell calls "latent capability ... the potential for acting, thinking, feeling or becoming " (1972) has been mostly ignored. Yet this potential forms in integral part of the learner-as-system, and a systems approach can help reveal it.

3. The learner is an individual. In spite of recent interest in aptitude-treatment-interaction research, the idea of the homogeneity of the group still dominates in research and instruction. Differences between individual learners have long been accepted as fact. Yet individuality has defied analysis largely because it is the product of many different sources of variance. As a solution, Beaird sees an increase in interdisciplinary research requiring, because of its very nature, a systems approach, (1972, p. 157).

This paper is based on the assumption that a realistic understanding of the active, individual and often unquantifiable learner can only be gained through a systems approach to learning. In this, the ideas about to be put forward remain faithful to the essence of Stowe's and Beaird's contentions, and using these as a point of departure, the paper sets out

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to find a systems equivalent for the "processes of learning" side of Schalock's dichotomy. Systems models already exist for the manipulation of the conditions of learning, (Kaufman, 1972, Nord, 1971), and instructional developers are creating new ones all the time. The present paper therefore suggests a systems model for the processes of learning, which through its generality will be sufficiently all-embracing to describe the multivariate behavior of the individual learner in a rich multimediated environment. The model implies other assumptions, which all share this common root. These, briefly, are as follows:

1. The learner, like any other living organism, must be considered as a dynamic open system.
2. The model must explain the relationships between elements and mechanisms within the learner even at the expense of the clarity of definition of these elements and mechanisms.
3. The model must be general enough to transcend conflicting views and uncertainties about psychologial mechanisms.

With these aims in mind, we must now turn to an exmination of the present status of systems in learning theory, and decide what to keep and what to change in the elaboration of our model.

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The Cybernetic Model of Learning.

Von Bertalanffy, who first proposed general system theory in 1945, has criticized the domination of the human sciences by a model of man as robot, to the exclusion of other models of human behavior (1968, pp. 186-194). The image of man as a self-regulating automaton just does not account for those spontaneous, creative and apparently disequilibrated behaviors which even the most superficial observation show to be just as much part of humanactivity as progressive stability and increasing order. Von Bertalanffy concludes that the human being should be considered as an "active personality system", whose ambitions are not always utilitarian and whose development is not always attributable to homeostatic mechanisms (1968, p. 193). Although von Bertalanffy is already witnessing the abandonment of a strictly cybernetic model in some areas of science, the dominant metaphor in educational technology continues to display markedly cartesian characteristics.

To understand the cybernetic model of human behavior, we must return to an earlier remark made by von Bertalanffy that living organisms, and therefore learners, are open systems (1940, chapter 5, pp. 521-531). Open systems are said to have four essential characteristics: they take in and put out matter and energy; they achieve and maintain steady states; they tend to increase in order with time; on the human level, they conduct "extensive transactional commerce with the environment", (Allport, 1960). The exchange of

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material with the environment is clearly essential to all physiological and psychological development. It is, however, how this interaction affects the organism that requires further study. As suggested in the second and third of the above characteristics, the theory of the open system proposes that this exchange of material progressively brings the organism towards a condition of equilibrium, and allows it to achieve a higher state of order through increasing complexity and subsequent differentiation of parts. It is these two phenomena that have given rise to the picture of man living under the constant control of feedback and homeostatic mechanisms and "feeding on negative entropy" (Schroedinger, 1945, chapter 6). Mention of a few theories and models will provide illustrations of how this applies in learning theory.

At the basis of the cybernetic model of learning is information theory. The measurement of information, upon which this theory rests, uses a unit, the bit, which implies the progressive logarithmic elimination of alternatives to a given outcome (Miller, 1963). In other words, the first bit of information eliminates twice as many alternatives as the second bit, which in turn eliminates twice as many as the third. This produces a situation where a person is brought to complete knowledge of something by successive approximations. Each bit of information brings him closer to the criterion, but each step produces a smaller change in knowledge than the

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previous one. Represented graphically, the learning curve this situation produces is the familiar logarithmic curve, such as shown in figure one. It is clear from this curve that a

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Figure one about here
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point is reached where further information adds practically nothing to what has been learned. At this point, where the curve reaches an asymptote, a cognitive steady-state is reached. It is also clear that learning depends solely on the reception of information from the environment. The learner is seen as someone to be shaped and moulded, and as devoid of autonomous and spontaneous cognitive activity.

Applied to learning research, information theory has been extensively and successfully used in the study of human information processing, storage and retrieval. Useful summaries of some of these studies are provided by Broadbent (1965, 1966) and by Forgus (1966, pp. 132-142). The most important conclusionsdrawn from this area of research are probably more accessible in the models of human cognition and perceptual processes than in the research reports themselves. Though the distinction often appears arbitrary, these may be divided into models of information processing and models of memory. Examples of the former are Broadbent's

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information-flow diagram (1958, p. 299), Smith, Shoben and Rip's feature model of concept formation (1974), and Schalock's "multiple systems cybernetic information processing model" (1972, p. 61). Memory models based on information theory includes Frijda's synthetical model of long-term memory (1972), Shiffrin and Atkinson's model of long-term memory (1969), and the neural systems model implied by Kesner (1973). From what these models have in common it is possible to make the following deductions:

1. Human information-processing systems are often thought of in terms of man-made systems -- computers, libraries, etc. -- which may or may not furnish viable analogies of cognitive functioning.
2. Feedback and self-regulatory control mechanisms, again often conceived of in mechnical terms, are basic units of operation.
3. Equilibrium between the system and the environment is the goal aimed at by every system, and the system will keep on changing itself until this goal is reached.

Closer examination of one information-processing system, the TOTE unit, will illustrate how these principles apply.

The TOTE (Test-Operate-Test-Exit) unit, developed by Miller, Galanter and Pribram (1960, chapter 2), is an excellent example of the cybernetic model of human learning. Indeed, it proposes the feedback loop as the basic unit of all human behavior. The originality of the TOTE unit lies in

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a continuous process of monitoring and adjusting input until any incongruity between it and criteria established in the organism has been removed. The unit is illustrated in figure two. Any stimulus that an organism receives,

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Figure two about here
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-- information received by the learner, for example -- is tested against an "image" that the organism has in the form of relevant empirical knowledge. If an incongruity is found, the organism performs an operation to correct it. The test phase is reapplied, and if the incongruity persists, another operation is carried out and tested. The process repeats itself until the incongruity disappears. What is important is that the operations of the organism are being constantly monitored and tested through feedback loops. Rather than identifying a sequence of discreet stimuli and responses, the TOTE unit describes the organism as being in a state of uninterrupted self-adjustment, until all incongruity is removed and it is stable. In other words, learning is defined as the shaping of an organism by progressively more accurate approximations to an "image", through the agency of perpetual feedback, arriving finally at a steady-state, where the input has been totally assimilated and the organism has returned to equilibrium.

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The TOTE unit reveals two fundamental weaknesses in the cybernetic model of learning. First, it presupposes that the normal state of the human being is homeostasis, and that the learner strives to eliminate all cognitive disequilibrium. However, observation of human behavior shows that homeostatic principles do not apply to "dynamic regulations... spontaneous activities...processes whose goal is not reduction but building up of tensions...processes of growth, development, creation," (Von Bertalanffy, 1968, p. 210). It is clear that these processes frequently play a role in learning. Second, it assumes that the learner's picture of the environment is gradually shaped by external stimuli in a process in which the learner plays no dynamic role. However, human behavior includes a large amount of autonomous activity, where problems are actively scught out and where disequilibrium is deliberately created (Von Bertalanffy, 1968, pp. 208-210, Allport, 1961 p. 90). Such creative and dynamic behavior, often essential to learning, cannot be accounted for by the cybernetic model.

The two concepts of disequilibrium and activity will be developed in the next section. But for the moment, we must conclude that the human organism is more complex than a machine, and that the cybernetic model cannot account for the active and dynamic aspects of its functioning.

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The Learner as "Active Personality System".

Von Bertalanffy's definition of the human being as an "active personality system" (1968, p. 193) implies both activity and organization. These two attributes of the learner will be examined in turn.

The learner as "active"

The champion of the learner as intellectually active and dynamic is undoubtedly Jean Piaget. Although the concept of equilibrium is again to be found in Piagetian theory, it is seen here as a dynamic process of "equilibration" always implying activity on the part of the learner. The purpose of this activity is to assure compensation for external intrusions upon the individual. Piaget writes, "A structure is in equilibrium to the extent that the individual is sufficiently active to be able to counter all intrusions with external compensations," (1968a, p. 151). The mechanisms through which these compensations are achieved are the assimilation of reality to existing schemata and the accomodation of these schemata to the actual situation (Piaget, 1968b, p. 103). These twin processes create and modify cognitive structures, which make real events and objects "known" to a person in a way clearly described in the "knowing circle" (Furth, 1968). Piaget concludes that

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development, and consequently learning, have equilibration as a basic mechanism "since all behavior tends towards assuring an equilibrium between internal and external factors or, speaking more generally, between assimilation and accomodation"(Piaget, 1968b, p. 103). It is, of course, assimilation, implying the adaptation of stimuli to existing structures in the organism,that is largely unexplained in the cybernetic model of learning. An open-system model, however, must account for this process.

Contrary to what the cybernetic model of the learner suggested, permanent equilibrium is the exception rather than the rule in Piaget's theory of human learning and development. Indeed, Piaget claims that of all the areas of human intelligence, it is only with the logico-mathematical structures that the achievement and maintainance of a state of permanent equilibrium is possible. Once acquired, these structures remain stable for life (Piaget, 1968b, p. 104). This means that in other domains of human development, either equilibrium is never achieved, or if achieved it is only a transient step in a much greater sheme of general development, and is soon disequilibrated by other intrusions. When equilibrium does not exist between internal and external factors, then either assimilation or accomodation will dominate over the other. When assimilation of external factors to existing concepts is favored, the

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individual's activity corresponds to play; and when on the other hand accomodation of the individual to external influences dominates, the individual's behavior is largely imitation (Piaget and Inhelder, 1969, p. 58). This apparent bipolar conception of imitation and play has been criticized for being to simple an approach to the question (Sutton-Smith, 1970, p. 139). However, taken generally these are important concepts for the present discussion and will be referred to again.

Piagetian theory can therefore tell us two things about the activity of the learner. First, activity is basic to all human learning and intelligence. Second, this activity leads to permanent equilibrium only in a minority of cases. This leaves a wide area of cognition in a state of disequilibrium, or where equilibrium is an ephemeral condition -- where, in fact, either assimilation or accomodation dominates over the other.

Autonomous activity and disequilibrium can perhaps best be observed in the way individuals perceive and interpret phenomena differently. The assimilation of information to existing structures requires interpretations of objects and events to be made according to the experiences, feelings and opinions of the individual. Although our perception influences what we think, Fleming underlines that what we think and know has a decided influence on how we perceive (1970). There is therefore a great

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variability in the way each individual perceives and interprets information. Olson, for example, bases his cognitive theory of semantics on this proposition, and supplies both logical and empirical support for the conclusion that meaning, and therefore the learning of meaning, depend ultimately on the imagination construed as "the ability to intellectually rearrange our perceptual experience" (1970, p. 260). While seconding certain important aspects of Piaget's theory, Olson's research leads us to conclude that the individuality and the imagination of the learner must always be bornein mind when considering him as an "active personality system".

The learner as "system"

To say that the learner is a system is to imply that he is cognitively organized and structured. It cannot therefore be claimed that "the learner-as-system" is a new idea. Gestalt psychology's notions of "field" and of "gestalt" itself, cognitive approaches to structure, such as proposed by Mandler (1962), and Piaget's use of the term "structure" all imply wholes, or linkages, or organization. Indeed Piaget's listing of the characteristics of a structure as wholeness, transformation and self-regulation (1970, pp. 1-6), and Brainerd's exegesis of

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the same concept, correspond exactly to the way in which we usually conceive of "system".

As an interconnected complex of knowledge, opinions, perceptions, feelings, intuitions and fantasies, the cognitive structure of the human learner has proved difficult to measure, to model or even to define. Yet in spite of the difficulties, attempts have been made to quantify structure, for example through the development of various indices of clustering in free recall (Dalrymple-Alford, 1970, Frankel and Cole, 1971, Roenker, Thompson and Brown, 1971). In addition, Hammond and Summers (1972) developed a quantitative denotation of knowledge as the correlation between a criterion and a judgment, and Leeuwenberg (1971) proposed a formal coding language which permits the quantification of information present in two and three dimensional shapes and in auditory patterns. However, the usefulness of each of these measures is limited to particular research areas, and none can serve the purposes of a more general systems picture of learning. Although more general measures are theoretical and less applicable, it is best if we turn to one of these to describe cognitive structure. This is Garner's measure of structure in terms of information uncertainty (1962).

Taking information theory as his point of departure, Garner proposes that structure can be quantified by

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predicting the uncertainty present in interrelated variables from other variables. This uncertainty, measured like information in bits, is given in its simplest form as $U(x) = -\log_2 p(x)$, where $p(x)$ is the probability of a given outcome, x, (Garner, 1962, p. 20). This is, of course, identical to the general formula for information measurement (Miller 1963). What is more important, however, is that Garner postulates uncertainty which can be attributed to many different sources at once and which can act simultaneously on many dimensions within the individual. Uncertainty in its most complex and most complete form is what Garner calls "joint multiple contingent uncertainty", $U(x,y:v,w)$, which is defined as "the amount of uncertainty of a joint criterion variable which can be predicted from a joint predictor variable" (Garner, 1962, p. 137). It is, in the learning context, an estimate of the uncertainty, or structure, of a combination of interrelated variables within an individual brought about by a combination of external factors acting simultaneously on that idividual. In theory, the number of criterion and predictor variables, or internal and external factors, can be limitless. Joint multiple contingent uncertainty, and measures connected with it, therefore imply changes in structure brought about by the interaction of two systems: the learner, who consists of a tightly

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integrated bundle of many different variables; and his environment, which likewise is made up of a large quantity of factors, each intertwined with the other.

Methodlogically, the estimation of joint multiple contigent uncertainty is achieved through the statistical techniques of multivariate analysis. However, such measures become meaningless when the number of variables in the two systems is more than just a few. What is important though is to be found at the conceptual level. Garner has provided a model of the human learner and his environment which allows both to be considered as systems of great complexity. We know for a fact that this corresponds closely to the actual state of affairs.

In summary, it is obvious that any model of the learner as a dynamic open system must account for the following phenomena:

1. The activity of the learner, as seen in the assimilation of and accomodation to environmental stimuli.
2. The individuality of the learner, evident in the influence of what he knows and feels (existing structures) on how he perceives and interprets incoming information.
3. The cognitive structure of the learner, defined as a complex system of inetrrelated variables.
4. The possibility for the learner to achieve or not to

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achieve a state of equilibrium in the face of his environment. Both options of a steady-state or of disequilibrium must be left open as alternative outcomes of learning.

Such a model will now be proposed.

A Model of the Learner as a Dynamic Open System.

Descriptive models of open systems are as numerous as the different levels of complexity open systems exhibit. Many of these models, like the simpler open systems they describe, have at their basehomeostatic mechanisms leading to the inevitable steady-state. Models describing phenomena analagous to the active and complex learner in an environment rich in sources of information are to be found among models of the more complex type of open system. These are the models of the living organism, and more especially of the growth of the living organism. This is not necessarily to say that learning is growth. What is suggested rather is that human learning is analogous to the growth of the living organism. In other words, learning brings about change in the learner, but not necessarily change in the direction of a steady-state.

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Working on the assumption that the growth of an organism is the difference between the synthesis and the degeneration of its parts, von Bertalanffy arrives at the following equation for the growth of an organism (1968, p. 173).

$$\frac{dw}{dt} = \eta w^n - \kappa w^m \qquad (1)$$

w is the weight of the organism, η and κ are constants of synthesis (anabolism) and degeneration (catabolism), and n and m are indices of the size-dependence of anabolism and catabolism respectively. After refinement to suit the requirements of certain principles of biology, this model produces both logarithmic and exponential growth-curves which respectively do and do not describe the organism as reaching a steady-state. Although conceived in the biological context, at a more general level vonBertalanffy's formula brings together elements present in all open systems -- the "weight" or size of the system, mechanisms which describe the "metabolism" of the system (synthesis, assimilation, breaking-down of elemets), and indices of the dependence of these mechanisms on the system's size.

It is on this more general level that we must construct our model of learning, by looking for cognitive equivalents for the terms in von Bertalanffy's formula. Cognitive "weight"

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could be defined in many ways -- as knowledge, aptitude, intelligence and so on. For the moment, though, we will define it as structure. The relationship between the amount of information a person receives and his cognitive structure has been established by Garner, as we have seen. Our measure of structure is therefore related to Garner's measure of uncertainty, and is a measure of certainty given by

$$C = \log_2 k - U \text{ bits} \qquad (2)$$

where k is the total number of perceived alternatives to a given outcome available to the learner, and U is the learner's joint multiple contingent uncertainty. The association of this measure of structure to Garner's complex measure $U(x,y:v,w)$ assures that it is a measure based on the interaction of many independent (predictor) variables. This measure also enables us to define learning more precisely, as the change of the certainty, or structure, of the learner.

The formation of such cognitive structures, as Piaget has explained, is attributable to the complementary processes of the assimilation of information to existing structures and the modification of these structures to compensate for external intrusions. While these two cognitive functions cannot be directly associated with biological mechanisms, they do resemble anabolic and catabolic processes to the extent that assimilation implies the synthesis and

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accomodation the reorganizing of cognitive structures. For η and κ in von Bertalanffy's equation we can therefore substitute a measure of assimilation E and a measure of accomodation K. The difference between E and K as multiples of C gives an estimate of the change in structure, or in other words of learning. Any attempt to quantify assimilation and accomodation is arbitrary. But if we assume that E and K are measures of the proportions of the incoming information that are assimilated to existing structures (E) and which change these structures (K), certain conclusions about them can be drawn which would hold true even if different measures of E and K were used. First, unlike η and κ, E and K vary. Put they do not vary independently of each other. As assimilation increases its dominance over accomodation in the learning process, accomodation decreases, and vice-versa. A learner cannot play and imitate at the same time. Since we are dealing with proportions, we can therefore say that at all times, $E+K=1$. Second, as Piaget has stated, cognitive equilibrium is reached at that point in learning where assimilation and accomodation are in balance. That is to say, the learner approaches a state of equilibrium as the difference between E and K decreases, a steady-state being reached when $E-K=0$. The terms EC and KC can therefore both for the content C and the formation (E-K) of cognitive structure.

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The variation of E and K and of (E-K) depends on existing structures. What we know determines what and how we learn just as what we learn determines what and how we know. It is therefore important to include terms for the dependence of assimilative and accomodative processes on structure in our model. These will be denoted by the exponents n and m respectively in keeping with von Bertalanffy's basic equation. Mathematically, n and m are given as

$$n=\frac{dE}{dt}:\frac{dC}{dt} \qquad (3)$$

$$m=\frac{dK}{dt}:\frac{dC}{dt} \qquad (4)$$

that is, as the ratios of the rates of change of E and K to the rate of change of C. These definitions are essentially the same as those given by von Bertalanffy (1968, p. 164).

The model of the learner as a dynamic open system emerges as a revised form of von Bertalanffy's equation,

$$\frac{dC}{dt}=EC^{n}-KC^{m} \qquad (5)$$

To repeat in summary, $C=\log_2 k-U$, where k is the total number of perceived alternatives, U is Garner's joint multiple contingent uncertainty, E and K are proportional measures of

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assimilation and accomodation, n and m are indices of the dependence of E and K on C, and t is a measure of time. It is important to note that the suggested definitions of these terms could at any time be replaced by other definitions of structure,"metabolism" and size-dependence of "metabolism". What is important is the relationship between these elements.

By making a few logical assumptions, this model can be simplified immediately. Since E and K covary (E=1-K), the dependence of E on C and of K on C have the same value, which means that n=m. Then

$$\frac{dC}{dt}=C^{a}(E-K) \qquad (5.1)$$

where the exponent a is a measure of the dependence of (E-K) on C, or

$$a=\frac{d}{dt}(E-K):\frac{dC}{dt} \qquad (6)$$

and (E-K) is a measure of the equilibrium of assimilation and accomodation, and thus of the equilibrium of the learner. In the simplest case we assume that the equilibrium of the learner (E-K) is directly dependent on his cognitive structure, C, in which case a=1. This means that the value of (E-K) increases at the same rate as C -- that

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assimilation and accomodation are increasingly disequilibrated. It must be noted that since the increase in structure indicated by changes in C is logarithmic, (E-K) must also increase logarithmically when a=1. In the case where increases in C bring the processes of assimilation and accomodation into progressive equilibrium, (E-K) decreases as C increases and if the rates of change are the same, a=-1. Again, (E-K) changes logarithmically, which means that for every bit of information that C increases, (E-K) decreases by half.

Let us now look at the learning curves the model generates. We have seen that the nature of the dependence of (E-K) on C (a=1 or a=-1) determines whether or not the slope of the curve $\frac{dC}{dt}$ is positive or negative. In addition, we must look at the corresponding function C=f(t) -- structure as a function of time. When a=1, (E-K) increases, C=f(t) is exponential, and a steady-state is not achieved. When a=-1, (E-K) decreases, C=f(t) is logarithmic, and a steady-state is ultimately reached. As can be seen from the curves of $\frac{dC}{dt}$ and of the corresponding curves of C=f(t) shown in figure three, the shape of the curve

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depends not only on the direction of a as indicated by its sign,

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but also on whether E is initially greater or smaller than K.

In case I, assimilation is greater than accomodation at the outset (E>K), but the difference between them decreases as C increases (a=-1). Since the negative exponent changes the basic formula to

$$\frac{dC}{dt}=\frac{(E-K)}{C} \qquad (5.2)$$

$\frac{dC}{dt}$ decreases, reaching an asymptote as it approaches zero. The corresponding function C=f(t) produces a curve of diminishing returns, and achieves a steady-state at some positive value of C. This is the familiar curve associated with the cybernetic model of learning.

In case II, assimilation is still initially greater than accomodation, but the difference between them increases as C increases. The positive exponent a=1 means that the basic formula may now be written

$$\frac{dC}{dt}=C(E-K) \qquad (5.3)$$

and since both C and (E-K) increase, $\frac{dC}{dt}$ does not reach an asymptote, but rather increases exponentially, giving for C=f(t) a curve of increasing returns, itself exponential.

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Cases III and IV represent the two corresponding situations where assimilation is smaller than accomodation ($\underline{E}<\underline{K}$). Since ($\underline{E}$-$\underline{K}$) will now always have a negative value, in these two cases $\frac{dC}{dt}$ will be negative. In case III, $\underline{E}$ and $\underline{K}$ are eveltually equilibrated and $\frac{dC}{dt}$ reaches an asymptote as it approaches zero. $C \Rightarrow f(t)$ also reaches a steady-state at $\underline{C} \Rightarrow 0$. In case IV, $\frac{dC}{dt}$ increases its negative value and $C \Rightarrow f(t)$ decreases exponentially and does not achieve a steady-state.

Cases III and IV may at first seem surprizing, for in both the reception of and compensation for new information causes a decrease in the certainty of the learner. At this point explanations can only be hypothetical. However, in both cases accomodation is stronger than assimilation, and it seems logical that the implied overcompensation for external stmuli (imitation) would cause a breaking-down and rearranging of existing structures. If each piece of new information causes a fairly severe cognitive reorientation and contradicts previous information already accomodated to, actual certainty would decrease. How often do we think we have grasped something only to receive further information that seems to contradict everything we have understood? Overcertainty based on insufficient information can only lead to decreasing certainty as the missing information is furnished.

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All of these cases are predicated upon the fact that changes in (E-K) depend on changes in C on a one-to-one basis, where a=±1. Any change in the numerical value of a will produce modifications in one of the four types of learning curve. The most interesting of these implies the most radical change. This is the case where E and K do not vary at all, where the proportions of assimilation and accomodation are constant. This produces a rather special situation, for now that (E-K) is constant (=b), and

$$\frac{db}{dt}=0 \qquad (7)$$

then

$$\frac{db}{dt}:\frac{dC}{dt}=0 \qquad (8)$$

or a=0. The model now becomes

$$\frac{dC}{dt}=(E-K) \qquad (5.4)$$

and is therefore also constant. The curve C=f(t) is a straight line, as seen in figure four. Negative values of

- - - - - - - - - - - - -
Figure four about here
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$\frac{dC}{dt}$ are also possible.

Apart from this radical and highly unlikely case, changes in the value of a will change only the slope, not the direction and basic shape of the learning curves. Even in instances where changes in (E-K) are only partly attributable to changes in C, we still have just four basic curves. To these correspond different learning types, which we will identify as logarithmic or exponential according to the sign of a, and as positive or negative depending on the sign of (E-K). Reference to the four cases in figure three will show that case I represents the logarithmic-positive learning type, case II exponential-positive, case IIIlogarithmic-negative, case IV exponential-negative. From this it is clear that the model covers all types of learning, and that the limitless possibilities of combining the four basic learning types in any order and in sequences of any length should allow for all observable learning behaviors.

The model appears to meet all the criteria implicit in the notion of the learner as a dynamic open system. The variability of E and K describes an active and dynamic organism. The exponential learning types, both positive and negative, illustrate instances where a steady-state is not the sure outcome of learning. The exponent a is ultimately a measure of the dependence of the learning processes on existing cognitive structures. The term C can be derived

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from a few or from an almost infinite number of inter-related variables, and thus permits a picture of the learner as a system of great complexity. As a whole, the model can account for all types of learning. These facts give the dynamic open-system model of the learner a distinct advantage over the cybernetic model. Educational technologists, who more than other educational researchers are preoccupied with creating rich and complex learning systems, should be among the first to exploit this advantage.

Implications of the Model for Educational Research

What follows is largely speculative. Attempts will be made, though, to tie the principal ideas put forth to established research. True to Stowe's and Schalock's contentions, outlined at the beginning of this paper, we shall look at possible areas of inquiry both in the processes of learning, as described by the model, and in the relationship between these processes and the manipulation of the conditions of learning by educational technologists.

Definition of the variables in the learning process.

An area of inquiry that has to be developed is the definition of structure C, of equilibrium (E-K), and of

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the relationship between them a. It must be repeated that the definitions of these terms given above are illustrative and that other measures may prove more useful in certain situations.

One definition of structure, C, has already been suggested, based on Garner's measure of uncertainty (1962). Factor analysis research, built around Guilford's "structure-of-intellect model" (1956) suggests a second possibility -- that structure might be defined in terms of loadings on certain defined intellectual factors. Factor analysis has already been used successfully to measure the relationship between learning and general ability factors (Dunham, Guilford and Hoepfner, 1968), and between success on a study-and-remembering task and sixteen intellectual aptitude factors (Hoepfner, Guilford and Bradley, 1970). It has also been used to identify transformation abilities in the structure-of-intellect model (Hoepfner, Guilford and Bradley, 1968), and the basic properties of categories in semantic memory (Herrmann, Chaffin and Corbett, 1973). We therefore know that basic factors exist and how to measure them. We know that they relate to learning ability. It remains to develop a reliable methodology for using loadings on these factors as a measure of structure.

In the area of word association, such a methodology has been developed by Deese (1965). The structure of

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meaning is defined by Deese as the loadings of individual words on factors extracted from a list of words associated with each other. The resulting associative network has a well-defined and quantifiable structure. Deese's techniques, along with the studies of Guilford and his associates, hold out great promise for the use of factor analysis as a tool for measuring structure not just in verbal learning, but in the more general multivariate form it takes in the model of the learner as a dynamic open system.

The quantitative definition of assimilation and accomodation, E and K, and more especially of equilibrium, (E-K), proves more elusive. But compared with subjective estimates of whether the learner is "imitating" or "playing", the suggestion of Palmer (1970) has the potential of great empirical precision. Referring to Shuford, Albert and Massengill's (1966) development of refined psychometric techniques for measuring a learner's "degree-of-belief probabilities", Palmer suggests that any measure of confidence will serve to provide an operational definition of equilibrium (1970, p. 20). In other words, equilibrium could be defined as the probability that a learner assigns to a particular phenomenon, outcome or response. In this case, (E-K) would be a measure of probability rather than the difference between two proportions. Of course, such a

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substitution would require a mathematical realignment of elements in the model -- with (E-K) as a proportion, a zero value would indicate equilibrium; but as a probability, equilibrium would be indicated by unity. Conceptually, however, the idea has great promise, and studies should be made of the applicability of measures of confidence to the equilibrium of learning processes.

Once C and (E-K) have been quantified, it should be relatively simple to determine experimentally the value of a. With equilibrium as the dependent variable, structure could be manipulated, for example by means of varying the amount of information given about a phenomenon, and the relationship between the two could be analyzed. Significant variations of a from unity would undoubtedly open up a fascinating area of research into the nature of the dependence of assimilative mechanisms on cognitive structure.

Manipulation of equilibrium states.

An important property of the model is that it shows that change in cognitive structure can only be brought about when the learner is in a state of disequilibrium. A whole new area of research therefore invites the educational technologist to develop ways of disturbing cognitive equilibrium and to study the various effects of such unbalance on learning. Apart from research by Suchman (1964), where

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films were used to develop inquiry training in children by forcing them accomodate to new stiuations, little has been done to study the contributions of the various media to this area. Traditionally, research into the manipulation of equilibrium states has been closely tied to Piagetian developmental theory. It has been found, for example, that cognitive conflict accelerates the acquisition of the conservation of substance (Smedslund, 1961), and of number (Gruen, 1965, Palmer, 1966). It is essential to expand the study of the effects of disequilibrium on learning to include adult as well as juvenile subjects, all media and media combinations as potential "disturbers of equilibrium", and classrom as well as laboratory settings. The object of research of this type would be to establish how disequilibrium is related to all of the four learning types as a function of age, medium, setting, and so on, and not simply how to manipulate equilibrium states so as to produce a logarithmic-positive learning curve.

Content structure - cognitive structure

The effect of the manipulation of the structure of learning content on the formation of cognitive structure has been investigated to some extent. Shavelson (1972) ascertained from word-association tests interspersed between readings from a text on Newtonian mechanics that instruction

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leads to the formation of increasingly integrated cognitive structures. Wortman and Greenberg (1971), testing Mandler's (1967, 1968) hierarchical model of memory, showed that subjects gradually adopt a hierarchical structure provided them in multitrial free-recall. Basden and Higgins (1972) demonstrated that when no restriction is placed upon the number of categories a subject uses to aid in the free-recall of random lists, there is a positive correlation between recall performance and the number of categories the subject uses to structure the input material. For the most part, however, these studies have been limited to verbal material, and in addition the manipulation of content structure has aimed at creating equilibrated cognitive stuctures. It is necessary, in the light of the model, to carry out similar studies on structuring where the content material is presented in multi-mediated form, and where equilibrium is not always the goal. Shavelson's technique of interspersing association tests in instruction would be especially useful, permitting a fairly constant monitoring of structure change during a series of variously structured multi-mediated instructional sequences.

Instructional treatment and structure.

Another research area that needs to be broadened to include multi-mediated learning systems concerns the differential effects of instructional strategies on cognitive

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structure. Once again, the ground has been broken. Mayer and Greeno (1972) produced structurally different forms of the concept of binomial probability in learners as a result of teaching it either by calculating with the formula, or by learning the meanings of the variables in the formula. Similarly, Egon and Greeno (1973) demonstrated a difference between the way discovery and rule-learning alter cognitive structure. This type of research should be of special interest to the instructional technologist, preoccupied as he often is with the development of instrucitonal strategies. Working within the framework of the model, instructional technology research should take three tracks. The first of these would emphasize the interaction between aptitudes, or single factors in cognitive structure identifiable across groups of subjects, and multimediated treatments embedded in flexible instructional systems. Such relationships might be termed "aptitude-systems-interactions" (ASI). The difference between this and aptitude-treatment-interaction studies would be the multivariate nature of the treatment element, which might even be conceived as the total activity stimulating the learner in a classroom. The second approach would study the effects of single treatments on complete and individual cognitive structures, and not just on isolated aptitudes. The study of such structure-treatment interactions (STI) would have to be carried out with single learners, in order

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to avoid losing sight of important factors because of the need to generalize. Finally, it should be possible to study both phenomena at once, that is the effects of different instructional systems on different cognitive systems. Again, structure-systems interation studies (SSI) would best be conducted with individuals. In all of these three types of research, the generality of the model, the definition of the elements in it and of the relationships between them, and its ability to generate all of the four basic types of learning, would provide the new conceptual framework and working tools required by such new areas of research.

The developmental aspect.

A final area that merits investigation by educational technologists is the developmental dimension that inevitably runs through all that has been mentioned above. Rather than go into repetitious detail at this point, let us simply mention, for example, that the dominance of the type of attribute a learner seizes on during the perceptual phase of cognitive structure formation changes with age (Bach and Underwood, 1970). This finding alone suggests that both the process and product of structure formation differs from one stage of intellectual development to the next. The educational technologist should therefore study the relationships between the conditions and the processes of learning, between the environment and cognitive structure, at all age levels.

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Summary

In summary, it can be said that the main effects of the model on educational technology research would be to encourage the exploration of the relationships between the "macrovariables" of the learning process -- structure, equilibrium and so on, -- to study the effects of whole systems of variables on learning, and to look with equal attention at positive, negative, exponential and logarithmic learning types. While thus loosening up research in a way hinted at by Stowe (1973), the model also requires the study of individual learners in simple and complex settings. Because of its generality, the model would also seem to encourage research into the effect of complex real-life settings on learning. In this way, it could provide a conceptual framework for scientifically less rigorous, and consequently less limited research projects. The educational technologist more than any other educational researcher has to deal with the everyday reality of education and the design of functional instructional systems. The model of the learner as a dynamic open system can give a more realistic and more complete picture of learning, and hopefully he will coordinate his many resources and develop his instructional systems accordingly.

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Figure Captions.

Fig. 1. The relationship between information given and alternatives eliminated.

Fig. 2. The TOTE unit.

Fig. 3. Graphs of $\frac{dC}{dt}=C^{a}(E-K)$, (left-hand column), and of the corresponding function $C=f(t)$, (right-hand column), for cases where $a=1$, $a=-1$ and $E>K$, $E<K$.

Fig. 4. A special case of $\frac{dC}{dt}=C^{a}(E-K)$ and of $C=f(t)$, where $a=0$ and $(E-K)$ is constant.

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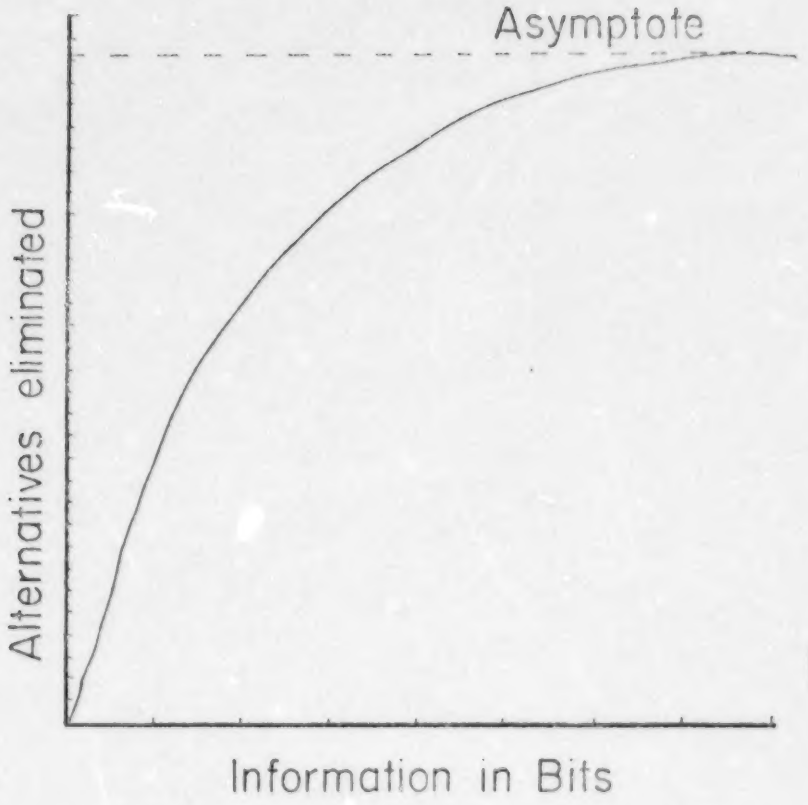

Fig. 1

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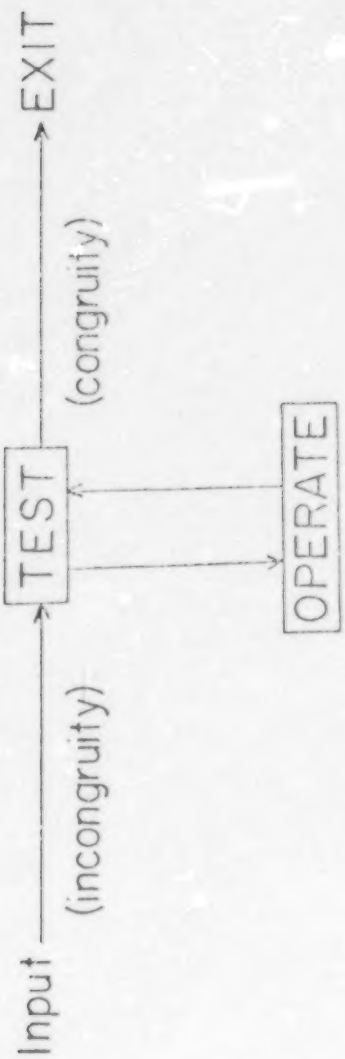

Fig. 2

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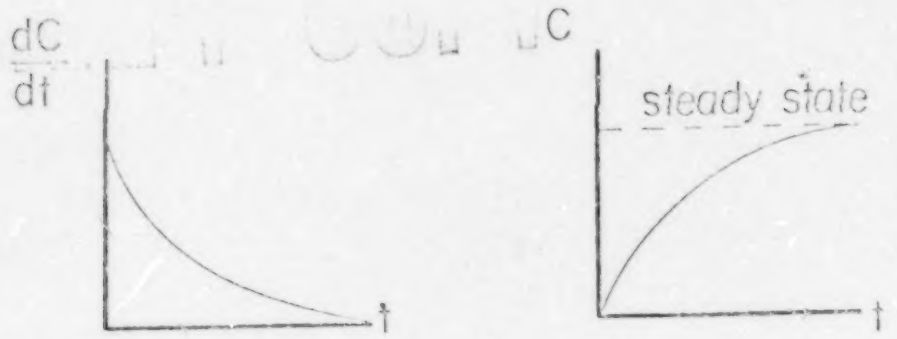
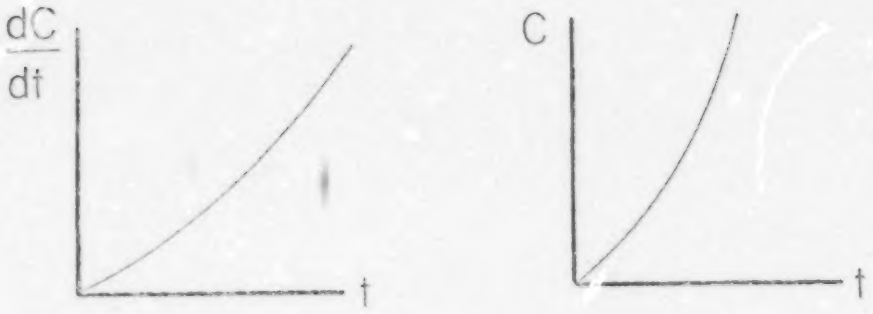
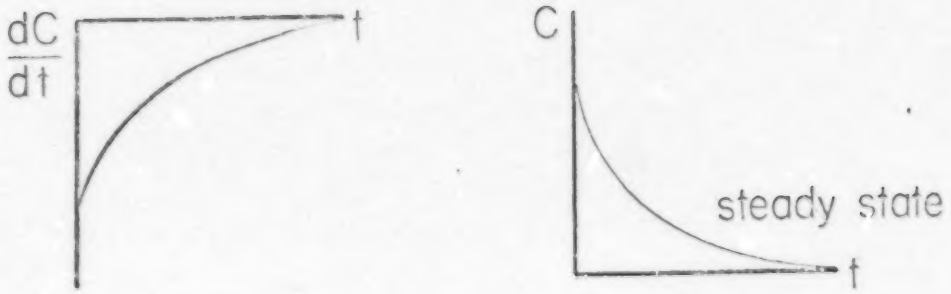


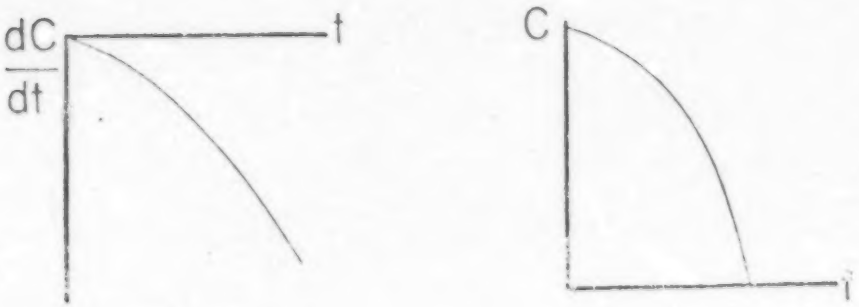
I. $a = -1$, $E > K$



II. $a = 1$, $E > K$



III. $a = -1$, $E < K$



IV. $a = 1$, $E < K$

Fig. 3

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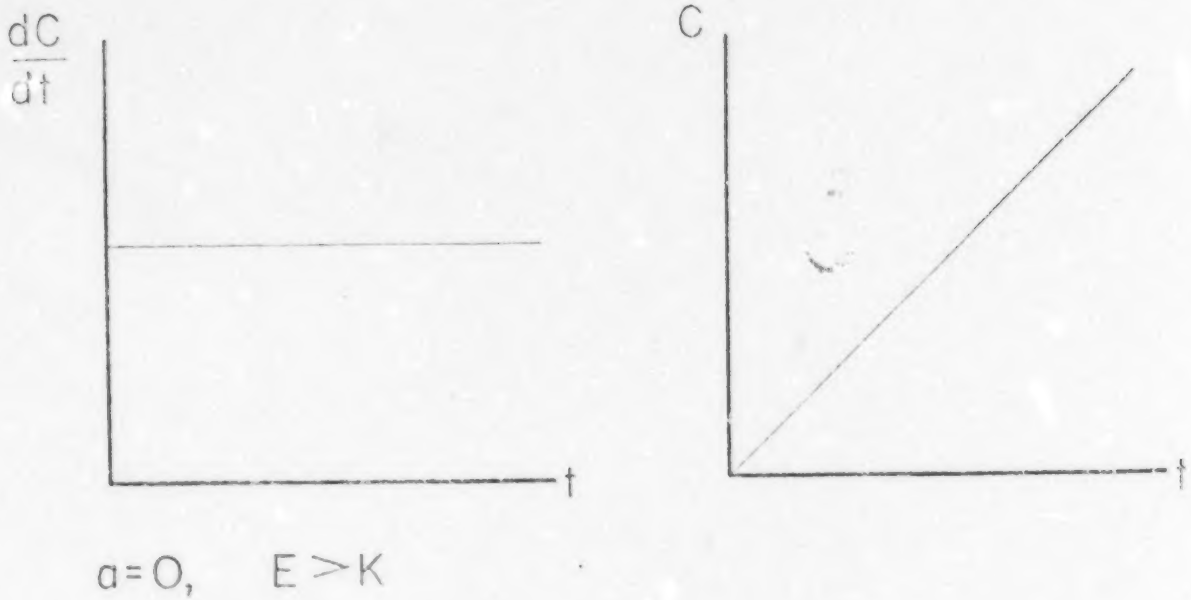

$a = 0, \quad E > K$

Fig. 4